TORNADOES ASSOCIATED WITH HURRICANES

As Illustrated by Franconia, Va., Tornado, September 1, 1952

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ABSTRACT

One of the tornadoes associated with Hurricane Able, 1952, occurred near Washington, D. C., and simultaneously with the upper air sounding made there. This led to a comparison between this particular tornado, along with others of similar environment, and conditions attributed to tornadoes in general. All such tornadoes associated with hurricanes have to date been observed only in the forward semicircle or along the advancing periphery of the tropical storm. The evidence is strong in favor of time of day having little relation to the occurrence of such tornadoes. A hypothesis is suggested wherein the weaker or nonexistent cyclonic horizontal wind shear of the environment may contribute to the lesser severity of these tornadoes. Unlike the typical tornado sounding, the limited evidence indicates the absence of (1) a low level temperature inversion, (2) sharp moisture stratification of dry air over moist air, (3) excessive instability.

INTRODUCTION

Three tornadoes occurred in connection with Hurricane Able [1] as it moved northward during the night and early morning of August 31–September 1, 1952 [1]. The first occurred the evening of the 31st in Stokes County, N. C. The other two struck the morning of the 1st at Franconia, Va., at 0330 GMT and Potomac, Md., at 0400 GMT. Potomac is about 11 miles northwest of Washington, D. C., and Franconia is 10 miles west-southwest of Washington. The tornado at Potomac could have been the same one which struck Franconia, for it moved toward the north-northwest. Details are available for only the Franconia tornado. Its path was surveyed on September 1 by a group of several meteorologists who agreed unanimously that there was positive evidence of a tornado having occurred.

A review of the synoptic conditions attending the Franconia tornado may be worthwhile because: (1) The time of occurrence coincided closely with both the 0300 GMT upper air soundings and the 0330 GMT surface observations. (2) The tornado occurred on the fringe of Hurricane Able. (3) No tornadoes or even severe thunderstorms were forecast. (4) The phenomenon of tornadoes associated with, or actually imbedded in, hurricanes is one of the most difficult and challenging problems facing the forecaster.

OTHER TORNADOES ASSOCIATED WITH HURRICANES

Tannehill [2] enumerated several tornadoes that were associated with hurricanes and Dunn [3] had some further comments concerning such occurrences and additional information on location and movement. All the tornadoes mentioned by Tannehill and Dunn have been grouped together in the first part of table 1. More recent tornadoes associated with hurricanes, as extracted from the *Monthly Weather Review*, are given in the second part of the table.

Dunn [4] claims "information is not available as to whether any particular quadrant is preferred," and Showalter [5] states they occur "in the dissipating stages of the storm overland" and quotes Mitchell, "in the right rear quarter of the tropical cyclone." However, the information in the remarks column of table 1 bears out the original statement by Tannehill [2], except for slight modification, namely, that this class of tornadoes has been observed only in the forward semicircle or along the advancing periphery of hurricanes.

Brooks [6] states that "over 80 percent of the tornadoes occur between noon and 9 p. m." In contrast, there appear to be sufficient reports of the time of occurrence, as listed in table 1 to warrant a tentative conclusion that the time of day has little relation to the occurrence of tornadoes associated with hurricanes. They are, of course, mostly outside the usual tornado season.

THE FRANCONIA TORNADO

A portion of the surface chart for 0330 GMT, September 1, which was practically coincident with the Franconia tornado, is shown in figure 1. The distribution of wind, precipitation, and other meteorological elements was typical for a tropical storm in this situation. At the time of the tornado, the speed of the storm center had increased to approximately 16 knots. This particular

[1] According to the intensity limits now in general use, Able, at the time of the Franconia tornado, should be classed as a tropical storm rather than a hurricane, the maximum surface wind force being over Beaufort 6, but under Beaufort 12 (see [3]).

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TABLE 1.—*Tornadoes associated with hurricanes*

Place	Date	Time	Remarks
(Compiled from Tannehill [2] and Dunn [3])			
Charleston, S. C.	1811		
Charleston, S. C.	1814		
Goulds, Fla.	Sept. 10, 1919	1308 EST	Moved E. to W., same direction as hurricane.
Ft. Lauderdale, Fla.	Sept. 28, 1929	No times available.	All these moved from SE. to NW. in direction of hurricane winds at the time. They possibly developed over the ocean as waterspouts.
Miami, Fla.	do		
Stuart, Fla.	do		
Boca Raton, Fla.	do		
Miami, Fla.	Oct. 4, 1933	Midnight and early morning of 5th.	At least one moved E. to W. while hurricane was moving NE. Tornadoes in NW. quadrant of hurricane.
Hollywood, Fla.	do		
Ft. Lauderdale, Fla.	do		
Cuba	Unknown	Unknown	
Bahamas	do	do	
(Extracted from Monthly Weather Review)			
Melbourne, Fla.	June 24, 1945	0257 EST	Along forward edge of hurricane.
Houston, Tex.	Aug. 28, 1945	2320 CST	Hurricane center 60 miles SW. of Houston at the time.
Miami, Fla.	Oct. 11-12, 1947	Night of 11th and morning of 12th.	Within northeastern portion of hurricane.
Appalachicola, Fla.	Sept. 19, 1947	0030 EST	On periphery of hurricane.
Ocala, Fla.	Sept. 23, 1947	0430 EST	On northern edge of hurricane.
Jacksonville, Fla.	do	0900 to 1100 EST.	On northern edge of hurricane.
Homestead, Fla.	Sept. 21, 1948	No time given	Occurred in NE. sector of hurricane.
Ft. Lauderdale, Fla.	Oct. 5, 1948	Late afternoon and early evening.	In forward edge of hurricane.
Appalachicola, Fla.	Aug. 30, 1950	1705 EST	Occurred in NE. quadrant of hurricane, moved toward the NW.
Jackson County, Fla.	Aug. 31, 1950	Early morning	Occurred in NE. quadrant of hurricane.
Stokes County, N. C.	Aug. 31, 1952	Evening	
Franconia, Va.	Sept. 1, 1952	0330 GMT	Along NErn fringe of hurricane; moved toward the north-northwest. Tornado at Potomac, Md., 0400 GMT may have been continuation of this one.

tornado seems to have occurred just outside the circulation of the tropical storm, in contrast to others that, in the past, have been reported well within the hurricane circulation. Note that the strongest surface winds along the periphery of the storm were observed to the northeast of the center.

A section from the corresponding 850-mb. chart is shown in figure 2. While the wind data are more sparse than usual on account of the storminess, the southeast wind of 45 knots at Andrews Field, Washington, D. C. (ADW), is the strongest in the neighborhood. It suggests the possibility of somewhat stronger anticyclonic horizontal wind shear in the area immediately to the northeast of Andrews Field, compared to other nearby points and, correspondingly, the least anticyclonic or even possibly some weak cyclonic horizontal shear just southwest of Andrews Field. The shear of the wind was selected for emphasis because many authors have associated shear with the formation of tornadoes. For example, Showalter [5] in speculating on the surface synoptic conditions accompanying tornadoes, mentions the prevalence of either cyclonic horizontal wind shear or cyclonic vorticity at the top of his list. Tepper [7] also postulates that a "zone of wind shear" would be

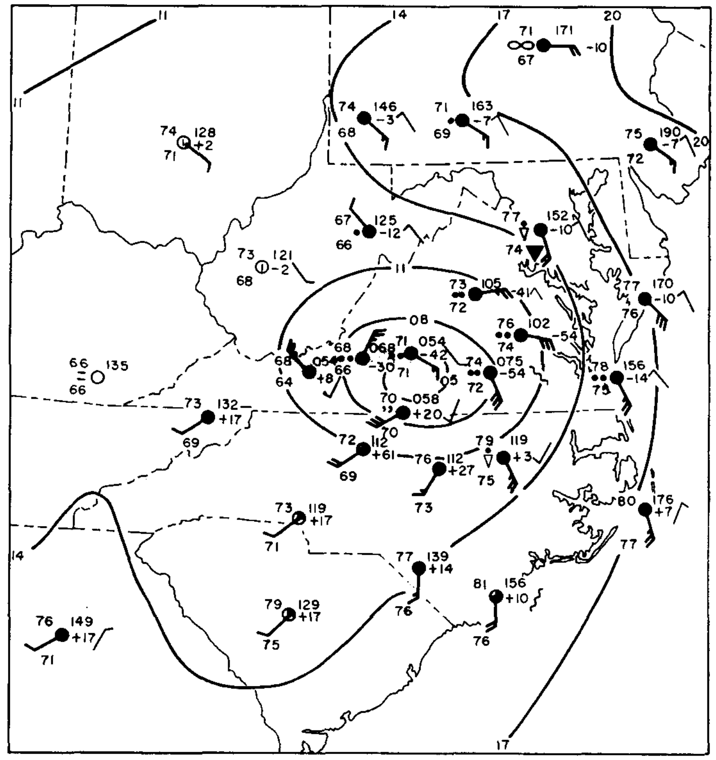

FIGURE 1.—Portion of surface weather chart for 0330 GMT, September 1, 1952. Location of Franconia, Va., is indicated by solid triangle.

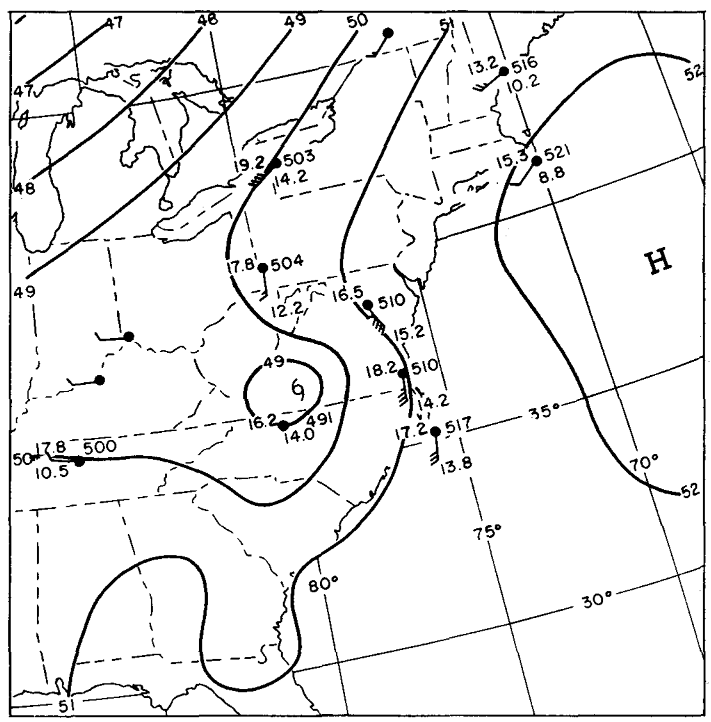

FIGURE 2.—Portion of 850-mb. chart for 0300 GMT, September 1, 1952. Solid lines are contours at 100-ft. intervals, labeled in hundreds of geopotential feet. Wind barbs show speed in knots (half barb=5 knots, full barb=10 knots, pennant=50 knots).

favorable for tornado formation. He indicates further [8] that his pressure jump hypothesis of tornado origin postulates a zone of "sharp wind shear," usually but not necessarily cyclonic wind shear, and that such shear is perhaps "only one of several mechanisms which may produce tornadoes."

Horizontal wind shear is involved in the definition of relative vorticity [9], as given by the equation

$$\zeta=\frac{V}{r}-\frac{\partial V}{\partial n},$$

"where V is the wind velocity, r the radius of curvature of the streamlines (r being positive in cyclonically curved motion), and n measures length along an axis at right angles and to the left of the wind direction." When the right member of the equation is positive, the vorticity is cyclonic. Now the curvature term, V/r, will be positive when the isobars or streamlines are curved cyclonically because, by definition, the radius of curvature is then positive. But the shear term, $\left(-\frac{\partial V}{\partial n}\right)$, may be negative in the case of a hurricane where, within a considerable portion of the storm, velocities increase on approaching the center. The resulting relative vorticity may then be negative or positive, depending on the magnitudes of the shear and curvature terms, as can also be seen from the following example. Referring to figure 1, Richmond, Va., happened to be approximately 100 miles from the storm center and had a surface wind force of Beaufort 6, or about 30 mph. These values give +0.3 per hour, approximately, for the V/r term. If then, $\partial V/\partial n$ at Richmond had been greater than 0.3 per hour, the relative vorticity would have been negative or anticyclonic, rather than cyclonic. If it is true that cyclonic horizontal shear is actually one of several conditions contributing to tornado formation, then the lack or lesser degree of such shear within portions of a hurricane may help to explain the impression, generally held by some forecasters [10], that tornadoes associated with hurricanes are less severe than others. We seem to have here another, even though remote case, as stated by Sutcliffe and Forsdyke [11], where "variations in vorticity due to shear are often as important as variations due to curvature . . ."

Conditions at the 700-mb. level (fig. 3) corresponded to those at 850 mb. and at the surface, with the greatest crowding of the contours and the strongest winds and wind shear being observed in the sector to the east-northeast of the storm center.

The sounding at Washington, D. C. (fig. 4), taken just prior to the occurrence of the tornado, is similar to soundings taken as a hurricane approaches (c. f. [4]). Furthermore, the temperature curve compares closely

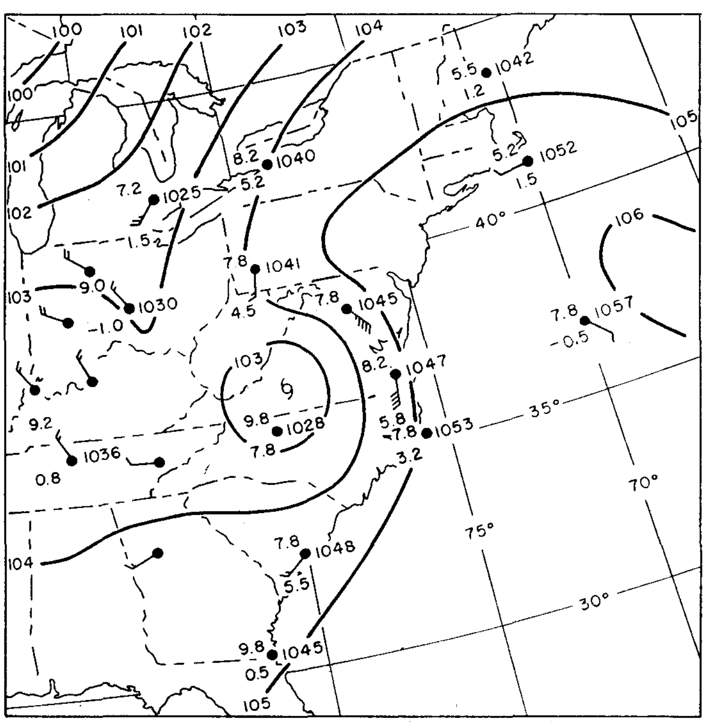

FIGURE 3.—Portion of 700-mb. chart for 0300 GMT, September 1, 1952. Solid lines are contours labeled in hundreds of geopotential feet. Wind barbs show speed in knots.

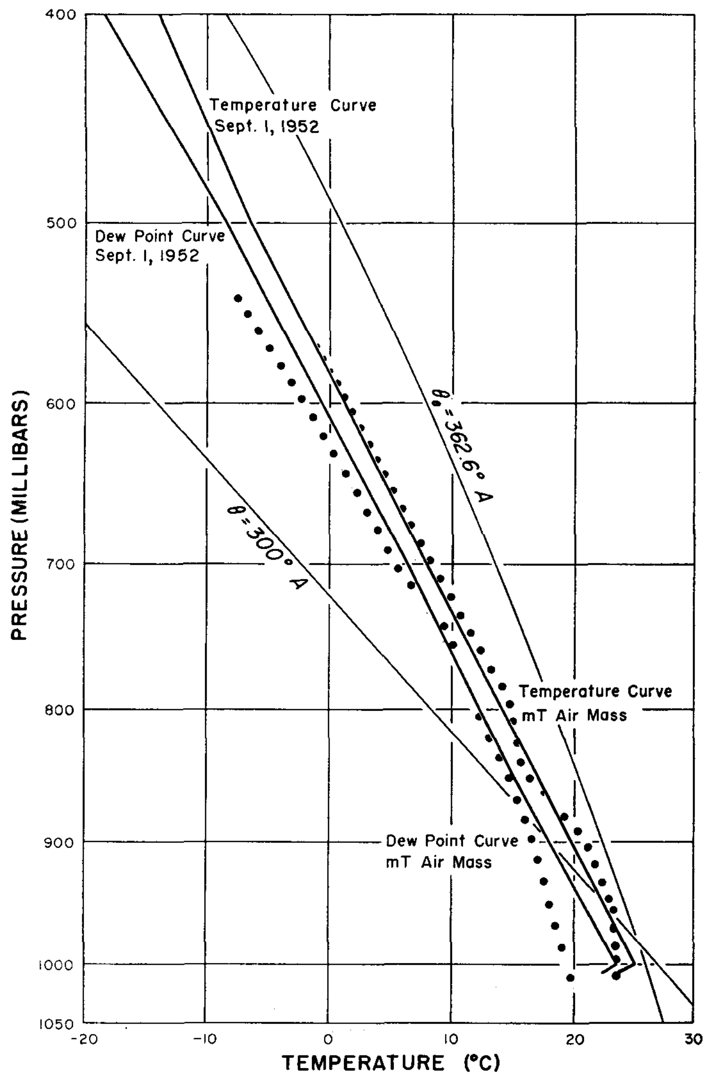

FIGURE 4.—Upper air sounding at Washington, D. C. (solid lines), 0300 GMT, September 1, 1952 (the time of the Franconia tornado) and typical mT air mass sounding at Washington (dotted lines) based on mean data from the summer of 1936 [12]. A dry adiabat (θ=300° A) and a moist adiabat (θ_e=362.6° A) are given for reference.

with the mean values for mT air in the summer of 1936 at Washington (fig. 4), as given by Berry, Bollay, and Beers [12]. The air was somewhat more humid than typical mT air, as would be expected in view of the deep cloud deck that prevailed at the time.

We next compare the sounding that is representative of the Franconia tornado with a mean tornado sounding, as given by Showalter [5] or Fawbush and Miller [13]. Actually, the differences between the two mean soundings are not significant, because Showalter presented his sounding as a typical one, not based on statistical averages [14]. It is of interest to note, in this regard, that the values of the various properties at the selected points, taken from the individual tornado soundings presented by Showalter [5], when averaged, compare very closely with the mean values obtained statistically by Fawbush and Miller.

Unlike the mean tornado sounding, as described by Fawbush and Miller (fig. 5), the Washington sounding indicates that: (1) There was no evidence of a low level temperature inversion, (2) there was no moisture stratification of dry air capping moist air, (3) the air did not appear to be excessively unstable. Some elaboration on point three follows.

The Showalter Stability Index [15] computed from the Washington sounding gave a value of zero which, while generally associated with sufficient instability for the occurrence of air mass thunderstorms and also thunderstorms produced by mechanical lifting, was relatively far from the value of −6, which has been "considered a reasonable criterion for an air mass in which tornadoes may occur" [16]. From figure 5, we observe that the lapse rate of the wet bulb temperature exceeded the saturated adiabatic lapse rate, particularly in the stratum from 1,000 mb. to 850 mb., and to a lesser degree in the 850-mb. to 700-mb. layer. These two strata, therefore, exhibited convective instability. A low level of free convection (LFC) is generally deemed to be associated with tornadoes. For the Franconia situation, the LFC was low being found at 840 to 875 mb., depending on the extent of the bottom stratum through which the mixing ratio is averaged; the humidity value was in the neighborhood of 15.5 gm. per kg. Some further evidence for instability was indicated by the thunderstorm reported

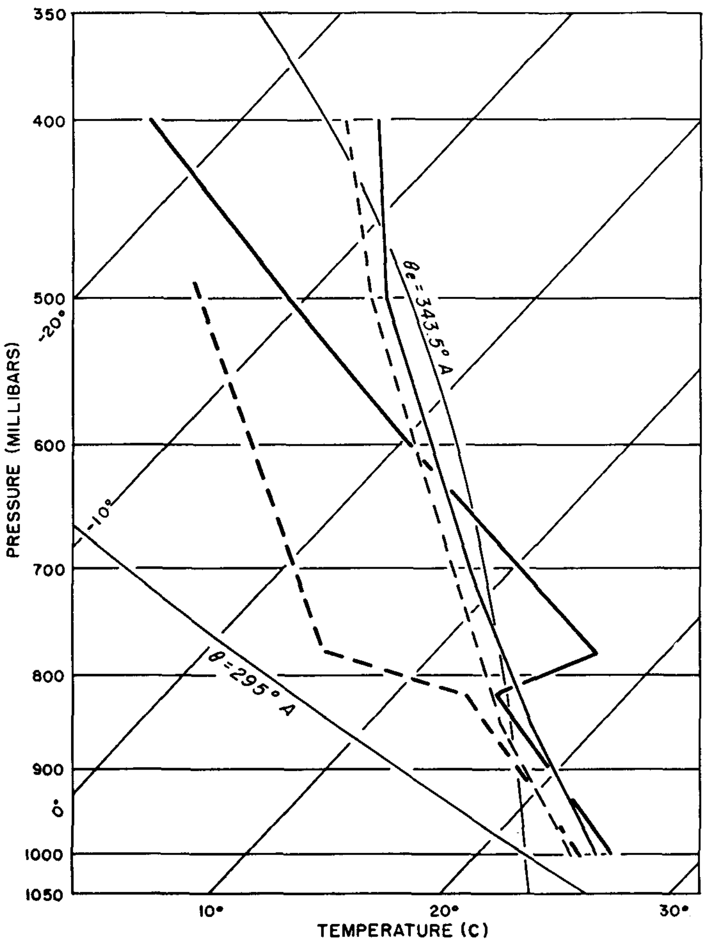

FIGURE 5.—Comparison of the Fawbush-Miller mean tornado sounding [13] (heavy lines) and the Washington, D. C., sounding at the time of the Franconia tornado, 0300 GMT, September 1, 1952 (thin lines), plotted on a U. S. A. F. skew T, log p diagram. Solid lines are temperature and dashed lines wet-bulb temperature. A dry adiabat (θ=295° A) and a moist adiabat (θ_e=343.5° A) are given for reference.

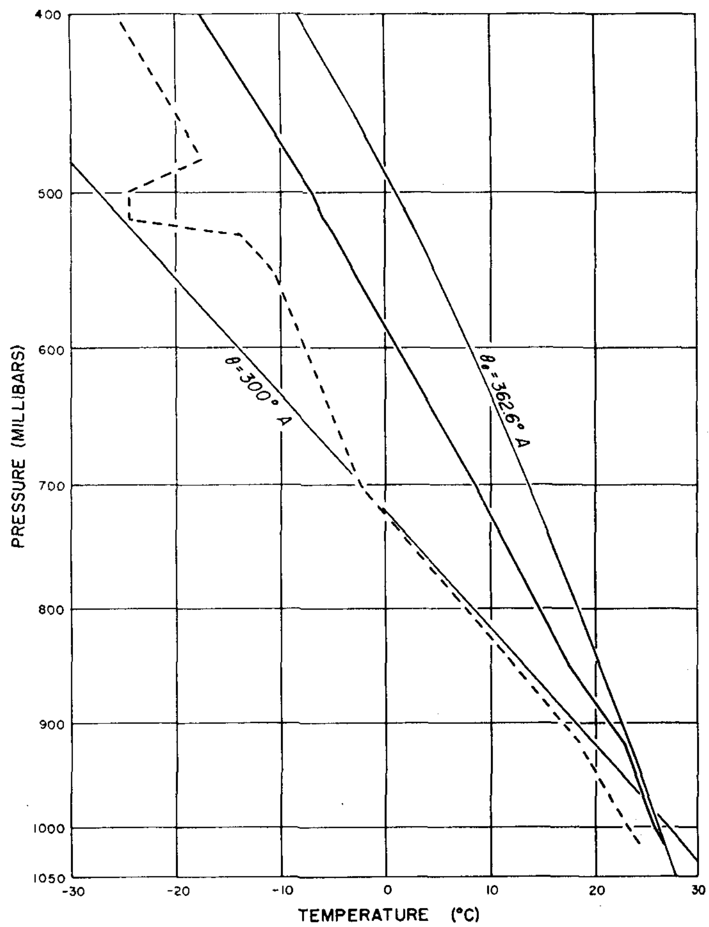

FIGURE 6.—Upper air sounding at Hatteras, N. C., 1500 GMT, August 31, 1952. Solid line is temperature and dashed line wet-bulb temperature. A dry adiabat (θ=300° A) and a moist adiabat (θ=362.6° A) are given for reference.

by Washington, D. C., to be south moving northeast, during a 9-minute interval, 0243 to 0253 GMT, September 1.

Latour and Bunting [17] have proposed that tornadoes may be associated with "wave" disturbances on the spiral bands within a hurricane—that such waves are caused by the intrusion of colder and drier air into the storm. Although the sounding at Washington (fig. 4), does not show any intrusion of dry or cold air, the sounding at Hatteras, N. C., at 1500 GMT, August 31, shows that the air was somewhat colder and significantly drier earlier and upstream (fig. 6). We do not consider that our data are of sufficient detail to test the hypothesis of Latour and Bunting.

CONCLUSION

These brief notes have indicated that several features, known to be associated with ordinary tornado conditions, are less evident or even absent in the case of tornadoes associated with hurricanes.

REFERENCES

1. R. B. Ross, "Hurricane Able, 1952," *Monthly Weather Review*, vol. 80, No. 8, Aug. 1952, pp. 138–143.
2. I. R. Tannehill, *Hurricanes*, Princeton University Press, Princeton, N. J., 1950.
3. Gordon E. Dunn, *Analysis and Forecasting of Tropical Cyclones with Special Reference to the Atlantic Ocean*, AAF Weather Wing, Asheville, N. C., May 1944. (Also issued by U. S. Office of Naval Operations as NAVAER 50–1R–169.)
4. Gordon E. Dunn, "Tropical Cyclones," *Compendium of Meteorology*, American Meteorological Society, Boston, Mass., 1951, pp. 887–901. (See p. 892.)
5. A. K. Showalter and J. R. Fulks, *Preliminary Report on Tornadoes*, U. S. Weather Bureau, Washington, D. C., 1943.
6. Edward M. Brooks, "Tornadoes and Related Phenomena," *Compendium of Meteorology*, American Meteorological Society, Boston, 1951, p. 673–679.
7. Morris Tepper, "Radar and Synoptic Analysis of a Tornado Situation," *Monthly Weather Review*, vol. 78, No. 9, Sept. 1950, pp. 170–176.
8. Morris Tepper, "On the Origin of Tornadoes," *Bulletin of the American Meteorological Society*, vol. 31, No. 9, Nov. 1950, pp. 311–314.
9. Sverre Petterssen, "Associations Between the Vorticity of the Large-Scale Air Currents and the Occurrence of Subsidence and Convection," *Bulletin of the American Meteorological Society*, vol. 30, No. 5, May 1949, pp. 191–192.
10. Wilfred P. Day, Personal Communication, U. S. Weather Bureau Airport Station, Washington National Airport, D. C., 1952.
11. R. C. Sutcliffe and A. G. Forsdyke, "The Theory and Use of Upper Air Thickness Patterns in Forecasting," *Quarterly Journal of the Royal Meteorological Society*, vol. 76, No. 328, Apr. 1950, pp. 189–217. (See especially p. 213.)
12. F. A. Berry, Jr., E. Bollay, and Norman R. Beers, *Handbook of Meteorology*, McGraw-Hill Book Co., New York, 1945, p. 619.
13. W. J. Fawbush and R. C. Miller, "A Mean Sounding Representative of the Tornadic Airmass Environment," *Bulletin of the American Meteorological Society*, vol. 33, No. 7, Sept. 1952, pp. 303–307.
14. A. K. Showalter, Personal Communication, U. S. Weather Bureau, Washington, D. C., 1953.
15. A. K. Showalter, "A Stability Index for Thunderstorm Forecasting," *Bulletin of the American Meteorological Society*, vol. 34, No. 6, June 1953, pp. 250–252.
16. Air Weather Service, "A Digest of Procedures Used by the Air Weather Service Severe Weather Warning (Thunderstorm) Center," *AWS Manual* 105–37, Nov. 1952, 63 pp.
17. M. H. Latour and D. C. Bunting, "Radar Observation of a Florida Hurricane, August 26–27, 1949," *Bulletin No. 29*, University of Florida, Engineering and Industrial Experiment Station, Oct. 1949.

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